International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Study and Analysis of Small Signal Parameters, Slew Rate and Power Dissipation of Bipolar Junction Transistor and Complementary MOS Amplifiers With and Without Negative Feedback Using T-Spice

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Abstract: *A feedback amplifier is one in which the output signal is sampled and fed back to the input to form an error signal that drives the amplifier. Feedback is a method in which a portion of the output returned to the input in order to modify the characteristics of the device. Feedback can applied to transistor amplifier circuits to modify their performance characteristics such as gain, bandwidth, input and output impedance etc.. There are number of ways by which a signal can be derived from output and can be returned to input*

Keywords: voltage gain, resistance, slew rate, power consumption, T-spice, feedback and amplifiers.

1. Introduction

An amplifier in which feedback is incorporated known as feedback amplifier. Feedback can divide in two categories depending upon the phase of the returned (feedback) signal with respect to the input signal. If the returned signal is in phase with input signal, feedback is known as positive feedback. It increases the gain of the amplifier but reduces the bandwidth and stability of the circuit. It used to produce oscillation. If the feedback signal is out of phase with respect to the input signal, it is known as a negative feedback. Negative feedback improves the performance of an amplifier but reduces the Overall gain. It helps to stabilize the gain, increases bandwidth: reduces distortions and assures the repeatability of the circuit performance. There are four types of feedback topology. These are voltage-shunt, voltage-series, current-shunt and current-series. In this paper I will analyze and compare the different characteristics of Feedback and without feedback amplifier circuit of BJT. After that I will compare the feedback amplifier of BJT with feedback amplifier of CMOS. Different waveforms will be finding out by manipulating different parameters in the circuit design and mathematical calculation and comparison will be done.

2. Tanner Tool

Spice is a general purpose circuit simulator capable of performing three main types of analysis: nonlinear DC, nonlinear transient and linear small-signal AC circuit analysis. Nonlinear DC analysis or simply DC analysis, calculates the behavior of the circuit when a DC voltage or current is applied to it. In most cases, this analysis is performed first. The result of this analysis is commonly referred to as the DC bias or operating-point characteristic. The Transient analysis, probably the most important analysis type, computes the voltages and currents in the circuit with respect to time. The third type of analysis is a small-signal AC analysis. It liberalizes the circuit around the DC operating point and then calculates the network variables as functions of frequency.

The T-Spice user interface consists of the following elements:

- Title bar
- Menu bar
- Toolbars
- Status bar
- Simulation Manager
- Simulation status window

3. Feedback Amplifier Circuit Using BJT and CMOS

I have done simulation of three circuits of with and without feedback amplifiers using BJT and CMOS with T-SPICE .After this I will calculate the value of different parameters of all circuits using AC analysis of T-spice. These parameters are input resistance (R_i), output resistance (R_o), voltage gain (A_v), current gain (A_i), power consumption and slew rate.

After this we will compare the all parameters of bipolar junction transistor (BJT) and complementary metal oxide semiconductor (CMOS) feedback amplifiers circuit.

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a. BJT amplifier circuit without feedback

I will consider a circuit of common emitter amplifier (CE) without feedback in this paper. The circuit of common emitter amplifier is shown in figure 1.

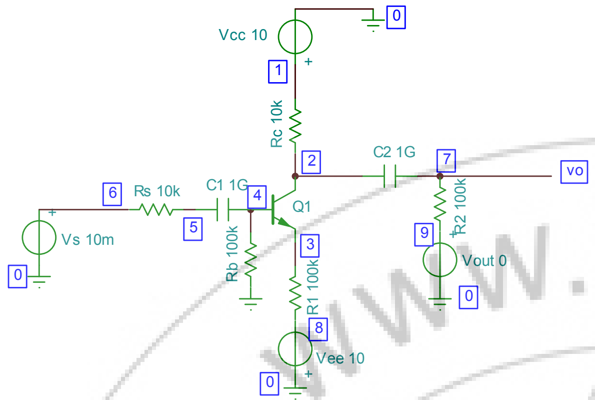

Figure 1: BJT amplifier without feedback

b. BJT feedback amplifier

I will consider a cascaded amplifier circuit as a BJT feedback amplifier circuit has shown in figure 2.

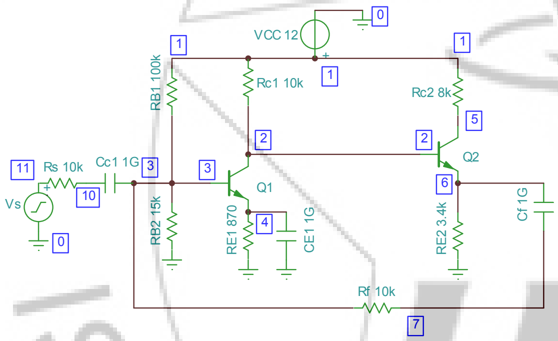

Figure 2: Cascaded BJT feedback amplifier

c. CMOS feedback amplifier

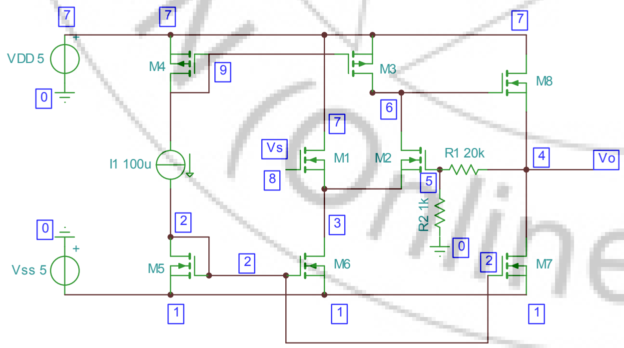

Figure 3: CMOS feedback amplifier

The CMOS feedback amplifier circuit shown in figure 3.

4. Parameters of with and Without Feedback Amplifier Circuit

The four small signal parameters of with and without feedback amplifier can be computed from these following formulas:-

Av = Vo/Vs, Ai = Io/Ii, Ri = Vi/Ii and Ro = Vo/Io

To obtain all four parameters, R_i , R_o , A_v and A_i, we will have to run two separate T-spice analysis one for computing the input current and the output Voltage for a known voltage applied to the input of the amplifier and the other for computing the current supplied by a voltage source connected to the output terminal of the amplifier when the input voltage source is set to zero.

Consider the application of a 10mV AC signal to the input of the amplifier. A DC input voltage signal would not be useful here because the input source to the amplifier is AC coupled . The frequency of the input signal should be chosen from the midband frequency range of the amplifier. With the choice of decoupling and bypass capacitors selected here (each selected very large), an input frequency of 1KHz is sufficiently midband. Both DC and AC analysis request are specified. The result of the DC analysis will provide us with the small-signal parameters of the transistor.

A. Detailed analysis of BJT amplifier circuit without feedback

We find that spice produces the magnitude and the phase of the input and output voltages and current of the amplifier. These are shown in figure 4 and 5. Figure 4 shows the linear waveform of CE amplifier and figure 5 show the decade waveforms of CE amplifier.

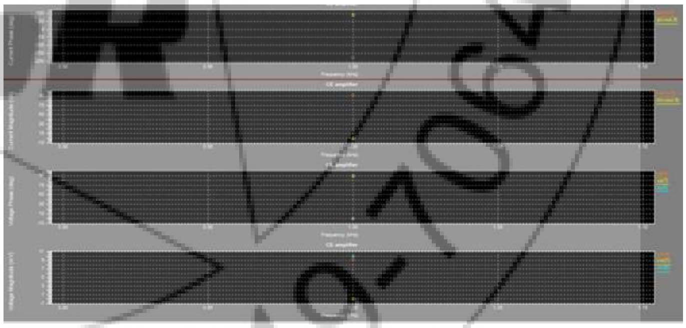

Figure 4: Voltage and current waveforms of common emitter amplifier (Linear)

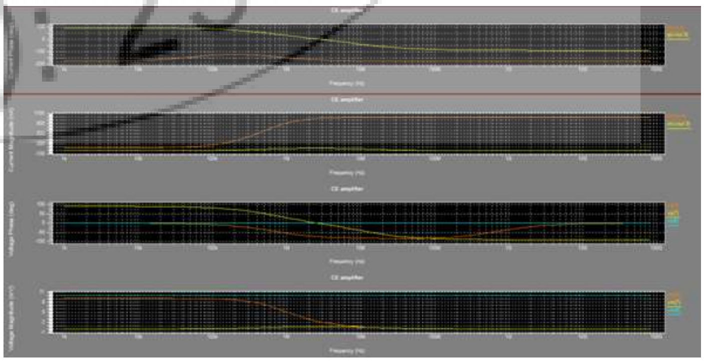

Figure 5: Voltage and current waveforms of common emitter amplifier (Decade)

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- Voltage Gain (Av)
  We obtained the different values for voltage gain calculation at 1 KHz frequency from waveforms which are shown in figure 4.
  $V_m(6) = 0.01V$ and $V_m(7) = 1.04V$ So we find that amplifier voltage gain
  $Av = V_m(7) / V_m(6)$ **= 104**
- Current Gain (Ai) (***Ai***)
  We obtained the different values for current gain calculation at 1 KHz frequency from waveforms which are shown in figure 4.
  $I_m(Vs) = 91.09 \times 10^{-9}A$ and $I_m(Vout) = 103.54 \times 10^{-6}A$ So we find that amplifier current gain
  $Ai = I_m(Vout) / I_m(Vs)$ **= 1.137 × 10³**
- Input Resistance (Ri) (***Ri***)
  We obtained the different values for input resistance calculation at 1 KHz frequency from waveforms which are shown in figure 4.
  $V_m(4) = 9.07 \times 10^{-3}V$ and $I_m(Vs) = 91.09 \times 10^{-9}A$
  So we find that amplifier input resistance
  $Ri = V_m(4) / I_m(Vs)$ **= 99.57 ×10³Ω**
- Output resistance (Ro)
  To determine the output resistance of this amplifier we repeat this same process but set the level of the input voltage source to 0V and increase the level of the voltage source in series with the load resistance to $10 \times 10^{-3}V$ AC.
  We obtained the different values for output resistance calculation at 1 KHz frequency from waveforms.
  $V_m(7) = 5.01 \times 10^{-3}V$ and $I_m(Vout) = 498.59 \times 10^{-9}A$
  So we find that amplifier output resistance
  $Ro = V_m(7) / I_m(Vout)$ **= 10.05 × 10³ Ω**
- Power dissipation (P_d)
  The total power dissipation in CE amplifier can be calculated by P=V*I. Here Power supply is from +10 volts to -10 volts that is equal to 20 volts and current at V_{cc} is 0.5×10^{-3} A. So power can be calculated as:
  $P_d = 20 \times 5 \times 10^{-4}$ **= 0.01 W**
- Slew rate (SR)
  It is defined as the maximum rate of change output voltage per unit of time and is expressed in volts per millisecond. In equation form
  $SR = dV_o / dt$ maximum V / microsecond.
  The slew rate is found to be **20.45** V/micro second, which is shown in figure 6.

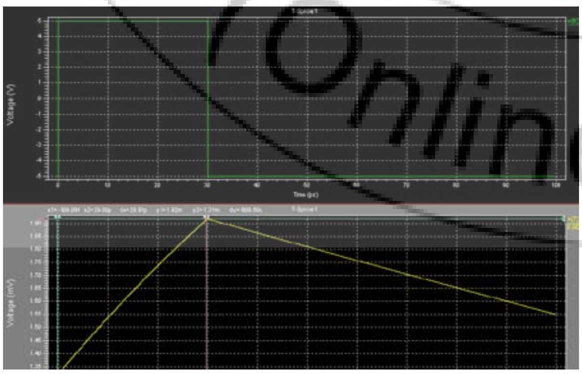

Figure 6: Slew rate waveform of common emitter circuit

B. Detailed analysis BJT amplifier circuit with feedback

We find that spice produces the magnitude and the phase of the input and output voltages and current of the amplifier. These are shown in figure 7 and 8. Figure 7 shows the linear waveform of BJT feedback amplifier and figure 8 show the decade waveforms of BJT feedback amplifier.

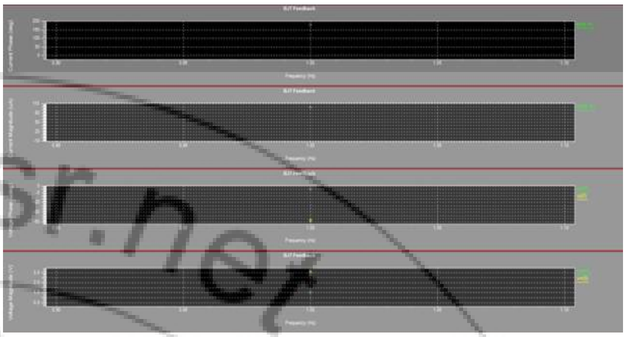

Figure 7: Voltage and current waveforms of BJT feedback amplifier (Linear)

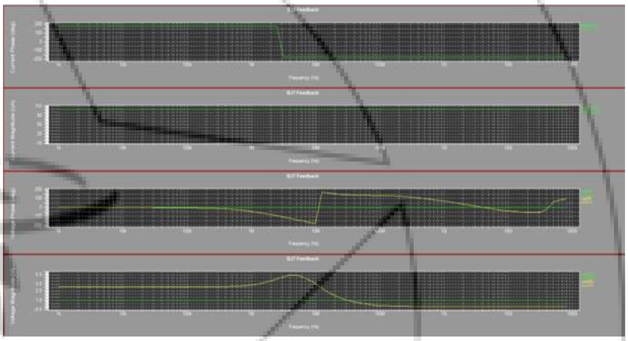

Figure 8: Voltage and current waveforms of BJT feedback amplifier (Decade)

- Voltage Gain (Av)
  We obtained the different values for voltage gain calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $V_m(11) = 1.0V$ and $V_m(5) = 3.09V$ So we find that amplifier voltage gain
  $Av = V_m(5) / V_m(11)$ **= 3.09**
- Current Gain (Ai) (***Ai***)
  We obtained the different values for current gain calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $I_m(Vs) = 100.47 \times 10^{-6}A$ and $I_m(Vout) = 41.60 \times 10^{-3}A$ So we find that amplifier current gain
  $Ai = I_m(Vout) / I_m(Vs)$ **= 0.414 × 10³**
- Input Resistance (Ri)
  We obtained the different values for input resistance calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $V_m(11) = 1.0V$ and $I_m(Vs) = 100.47 \times 10^{-6}A$
  So we find that amplifier input resistance
  $Ri = V_m(11) / I_m(Vs)$ **= 9.953 ×10³Ω**
- Output resistance (Ro)
  To determine the output resistance of this amplifier we repeat this same process but set the level of the input voltage source to 0V and increase the level of the voltage source in series with the load resistance to 1V AC.

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We obtained the different values for output resistance calculation at 1 KHz frequency from waveforms.
$V_m(5) = 3.09V$ and $I_m(Vo) = 9.78 \times 10^3 A$
So we find that amplifier output resistance
$Ro = V_m(5) / I_m(Vo) = \mathbf{3.195 \times 10^2\ \Omega}$

- Power dissipation (P_d)
  The total power dissipation in CE amplifier can be calculated by P=V*I. Here Power supply is from +12 volts to 0 volts that is equal to 12 volts and current at V_{cc} is $16.2 \times 10^{-4}A$ .So power can be calculated as:
  $P_d = 12 \times 16.2 \times 10^{-4} = \mathbf{195.12 \times 10^{-4}\ W}$
- Slew rate (SR)
  It is defined as the maximum rate of change output voltage per unit of time and is expressed in volts per millisecond. In equation form
  SR= dV_o / dt maximum V / microsecond.

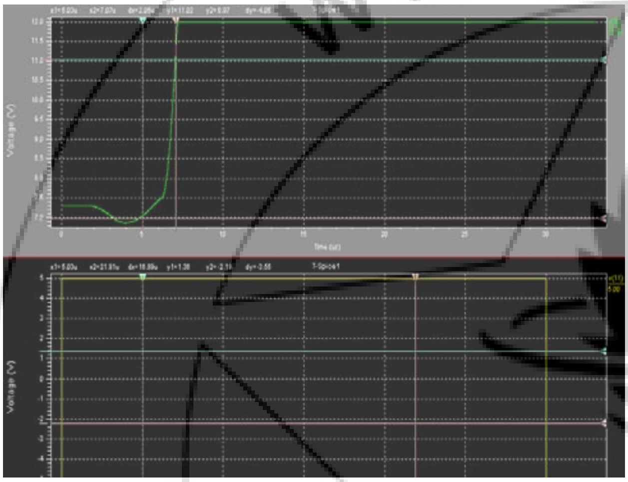

Figure 9: Slew rate waveform of BJT feedback circuit

The slew rate is found to be **1.976** V/micro second, which is shown in figure 9.

C. Detailed analysis CMOS amplifier circuit with feedback

We find that spice produces the magnitude and the phase of the input and output voltages and current of the amplifier. These are shown in figure 10 and 11. Figure 10 shows the linear waveform of CMOS feedback amplifier and figure 11 show the decade waveforms of CMOS feedback amplifier.

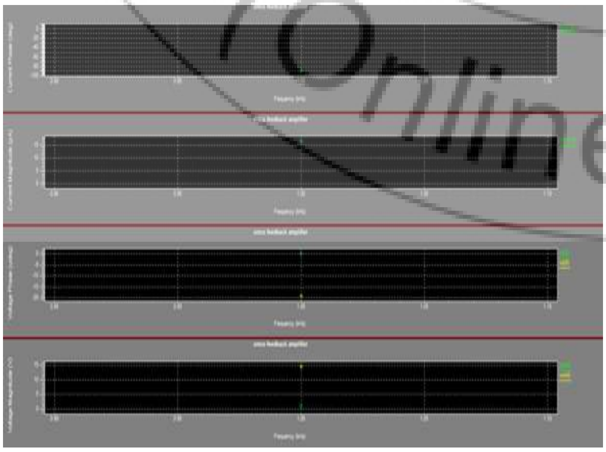

Figure 10: Voltage and current waveforms of CMOS feedback amplifier (Linear)

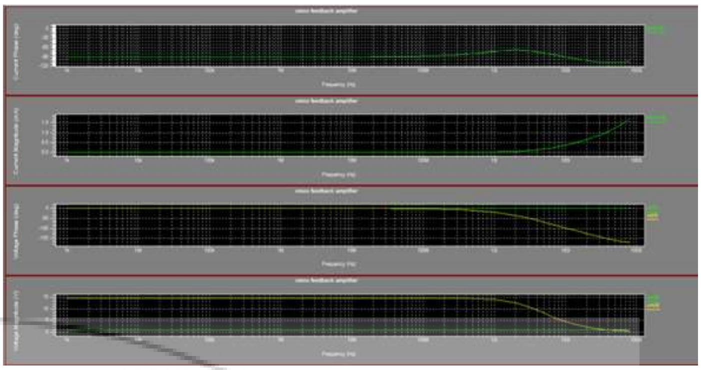

Figure 11: Voltage and current waveforms of CMOS feedback amplifier (Decade)

- Voltage Gain (Av)
  We obtained the different values for voltage gain calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $V_m(8)$ =1.0V and $V_m(4) = 0.1456\times 10^2V$ So we find that amplifier voltage gain
  $Av= V_m(4) / V_m(8) = \mathbf{0.1456\times 10^2}$
- Current Gain (Ai) (***Ai***)
  We obtained the different values for current gain calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $I_m(Vs)= 16.31 \times 10^{-12}A$ and $I_m(Vo) = 19.91 \times 10^{-3}A$
  So we find that amplifier current gain
  $Ai = I_m(Vo) / I_m(Vs) = \mathbf{121.1 \times 10^7}$
- Input Resistance (Ri)
  We obtained the different values for input resistance calculation at 1 KHz frequency from waveforms which are shown in figure 7.
  $V_m(8)$ =1.0V and $I_m(Vs)= 16.31 \times 10^{-12}A$
  So we find that amplifier input resistance
  $Ri = V_m(8) / I_m(Vs) = \mathbf{6.131 \times 10^{10}\Omega}$
- Output resistance (Ro)
  To determine the output resistance of this amplifier we repeat this same process but set the level of the input voltage source to 0V and increase the level of the voltage source in series with the load resistance to 1V AC.
  We obtained the different values for output resistance calculation at 1 KHz frequency from waveforms.
  $V_m(4) = 14.56V$ and $I_m(Vo) = 19.91 \times 10^{-3}A$
  So we find that amplifier output resistance
  $Ro = V_m(4) / I_m(Vo) = \mathbf{731.3\Omega}$
- Power dissipation (P_d)
  The total power dissipation in CE amplifier can be calculated by P=V*I. Here Power supply is from +5 volts to -5 volts that is equal to 10 volts and current at V_{cc} is $5.94 \times 10^{-4}A$ .So power can be calculated as:
  $P_d = 10 \times 5.94 \times 10^{-4} = \mathbf{5.94 \times 10^{-3}\ W}$
- Slew rate (SR)
  It is defined as the maximum rate of change output voltage per unit of time and is expressed in volts per millisecond. In equation form
  SR= dV_o / dt maximum V / microsecond.
  The slew rate is found to be $\mathbf{4.57 \times 10^4}$ V/micro second, which is shown in figure 12.

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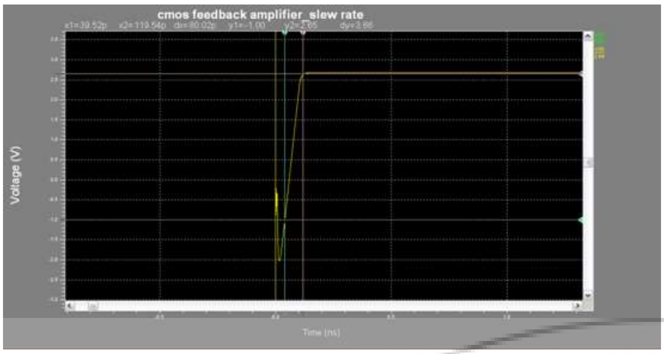

Figure 12: Slew rate waveform of CMOS feedback circuit

5. Results of BJT and CMOS Amplifier

A comparison of different parameters of BJT and CMOS with and without feedback amplifier is shown in table 1.

Table 1: Comparison table of different parameters of BJT and CMOS with and without feedback amplifier

S. No.	*Parameters*	*BJT amplifier without feedback*	*BJT amplifier with feedback*	*CMOS amplifier with feedback*
1	Voltage gain	104	3.09	0.1456×10^{2}
2	Current gain	1.137×10^{3}	0.414×10^{3}	121.1×10^{7}
3	Input resistance	$99.57\times10^{3}\Omega$	$9.953 \times10^{3}\Omega$	$6.131 \times10^{10}\Omega$
4	Output resistance	$10.05 \times 10^{3}\ \Omega$	$3.195 \times 10^{2}\ \Omega$	731.3Ω
5	Power dissipation	0.01 W	195.12×10^{-4} W	5.94×10^{-3} W
6	Slew rate	20.45 V/micro second	1.976 V/micro second	4.57×10^{4} V/micro second

6. Conclusion and Future Scope

In this paper I worked in two parts first I compared the BJT amplifier circuit without feedback and with the BJT feedback amplifier where I found that feedback is better to achieve less voltage gain and high current gain on the cost of high slew rate and more power consumption. In second part of my work I compared the BJT feedback amplifier with the CMOS feedback amplifier where I observed that CMOS feedback circuit is faster than BJT feedback circuit with a low power consumption. Therefore due to the importance of both the devices we switched on the new technology which is very efficient and well known now days that is Bi-CMOS technology. So we can further work on lots of researches in this field in which we can try to improve all the parameters further by utilizing the advantage of both the previous research results and can study further to enhance the capacity and efficiency of feedback circuit.

Now a days electronics circuit has major role of feedback. The project I have undertaken can be used as a reference or as a base for realizing the feedback circuit so it can be further implemented in other projects of greater level.

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